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AIRBORNE OCEAN ACOUSTIC MEASUREMENTS
A USER'S REPORT ON SUS RELIABILITY

NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PENNSYLVANIA

30 DECEMBER 1976

REPORT NO. NADC-76318-20

AIRBORNE OCEAN ACOUSTIC MEASUREMENTS: A User's Report on SUS Reliability

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30 DECEMBER 1976

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Prepared for
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The reliability of SUS (signals, underwater sound) explosives as acoustic sources is an important consideration when these devices are used in ocean propagation measurements. Records have been kept on the performance of many MK 61-0 SUS, set to fire at 800 ft depth, that have been launched from aircraft over the past several years in a series of propagation experiments. While the majority performed satisfactorily, a significant number detonated well outside of the intended depth range, did not explode, or exhibited

20. abnormally slow sink rates. Partial detonations also occurred, but infrequently. While the observed deficiencies do not render the current stock of SUS useless to the oceanographic community, the reliability of SUS procured in the future for ocean acoustic measurements might be improved by effecting minor design changes.

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SUMMARY

INTRODUCTION

Questions have recently been raised by the LRAPP (Long Range Acoustic Propagation Project) program management concerning reliability and suitability of currently available SUS as acoustic sources for ocean transmission measurements. The NAVAIRDEVCEN has accumulated firing statistics from many of the SUS used by this command for propagation loss measurements. The data indicate the degree of firing reliability and consistency that can be expected from stock SUS, and also indicate where design improvements may be needed in SUS produced in the future.

Over a period of six years, the NAVAIRDEVCEN has used more than 5000 SUS explosives in a series of acoustic propagation/bottom loss measurements sponsored under AIRTASK No. A370370B/001B/TF11-121-707, Work Unit No. ZU102, and others. The measurements have been conducted from aboard fixed wing aircraft using the SUS as inexpensive, impulsive, broadband, high energy acoustic sources in conjunction with receiving sonobuoys. Most SUS were MK 61-0 units set to fire at a nominal depth of 800 feet.

The following are factors regarding SUS performance that are important to the conduct and analysis of the acoustic measurements:

1. SUS to Sonobuoy Spacing - Estimation of spreading and attenuation losses, and of bottom reflection grazing angles, are dependent in part upon the accuracy of source-receiver spacing estimates. This subject has been examined separately.[1]

2. Firing Depth - The acoustic source level and frequency distribution of underwater explosion energy are dependent upon a combination of firing depth and charge weight.

3. Consistency of Elapsed Time Between Launch and Firing - The dependability of the time interval between launch and detonation determines, to some extent, the minimum shot-to-shot spacing that can be employed (an important consideration in the aircraft measurement procedure).

4. Firing Reliability - Refers to such factors as full versus partial detonation, total failure (dud), and extreme firing depth errors.

It is the intent of this technical note to present knowledge gained about the last three factors listed above; knowledge acquired from the examination of data from approximately 2700 SUS, or more than half of all the SUS expended in the NAVAIRDEVCEN acoustic measurement program.

The SUS that were used to compile the information in this document were drawn from various Navy weapons depots from time to time. Standard magazine launchers and free-fall chutes were used to launch the SUS. Nominal launch altitude was 5000 feet with an envelope of 4000 to 6000 feet. Ground speed during launches was maintained between 180 and 220 knots.

[1] *Gabrielson, T.B., 30 April 1976; Airborne Ocean Acoustic Measurements: Determination of Explosive Source to Sonobuoy Spacing. NAVAIRDEVCEN Report NADC-75344-20.*

SUMMARY OF RESULTS

For one or more reasons, approximately 20 percent of the MK 61-0 SUS sample population failed to perform as reliable acoustic sources. They were duds, they fired at depths outside of the specified firing depth range, they did not detonate fully, or they had an in-water sink rate that was abnormally low.

Sixty percent of those classed as firing failures, representing 12 percent of the sample population, were SUS that fired at a depth near 60 feet, instead of near the 800 feet nominal depth for which they were set. Thirty percent of the failures were duds. Only 15 SUS from the sample population appeared to have detonated at depths greater than 900 feet, and there was evidence that 12 of these did not detonate fully. The causes of 6.5 percent of the firing failures were uncertain or unknown.

The bubble pulse frequencies of 428 shots, composed of SUS from the larger sample population that fired normally and within an acceptable depth range, were measured to obtain more exact estimates of firing depth. Firing depth values from this smaller sample population formed a distribution that peaked at 800 feet and which had a mean firing depth of 794.5 feet. Ninety percent of the shots fired within the range of 735 to 850 feet.

In-water sink times and rates were estimated from measurement data. Value distributions of both quantities were bimodal. The sink time distribution peaked at 48 and 59 seconds, and all samples fell within the range of 42 to 72 seconds. The sink rate distribution correspondingly peaked at 16.75 and 13.75 feet/second, with all samples falling within the range of 12 to 18 feet/second. Specified sink rate and water-entry-to-detonation interval for the 800 foot setting are 16.8 feet/second and 46 seconds ± 5 seconds, respectively.

The mean sink time for a small sample population of MK 61-0 SUS, which was set for 800 feet but which fired near 60 feet, was 4.7 seconds, compared to a specified 3 seconds ± 1 second sink time for 60 foot SUS. This small difference is within tolerances imposed by the method used to calculate sink time.

A limited effort was made to uncover some possible correlation between SUS performance and production lot or source of supply (weapons depot). No consistent dependence was found.

Over the years, on successive acoustic measurement deployments, attempts have been made to reduce the incidence of duds, premature firing, and slow descent rates by modifying the SUS preparation and launch procedures. The hairpin wire, which disables the SUS's 60-foot firing piston when installed, has been double checked for security. When using aircraft free-fall chutes for launching, comparisons have been made between nose-first and tail-first drops, and between SUS with the arming wire/drag plate assembly installed and removed. No statistical differences in descent rate or firing performance have been discerned.

CONCLUSIONS

About 20 percent of the standard MK 61-0 SUS, set for 800 feet, failed to fire properly.

The majority of malfunctioning units apparently fired at the shallow (60 feet) depth setting. Since the depth setting wires in many SUS were checked before use and found to be adequately secured, it appears that the devices were failing in some manner. The shallow-depth piston that the wire secures may be forcing it aside or shearing through it, or perhaps the small portion of the piston that bears on the wire is breaking away. The first possibility seems most likely.

Duds are the second most significant type of firing malfunction. Shallow firing and duds together account for over 90 percent of the firing failures.

The number of firing failures categorized as over-depth or partial detonations is insignificant. This is also the case with SUS that detonated between the deep and shallow ranges.

Of the 80 percent that fired properly, 30 percent suffered from a noticeably slow in-water descent rate that increased the time from water entry to detonation by an average of 11 seconds (23 percent). The cause of the slowed descent rate is not known. Entangled arming wire/drag plate assemblies and bent tail finds are the only obvious possiblities. Since many SUS were dropped without the arming wire in place, with no apparent change in the distribution of descent rates, this does not appear to be a likely cause. Also, nose-first versus tail-first free-fall launching of the SUS appears to have no effect on the in-water descent rate distribution, i.e., if some SUS are being damaged upon exiting the free-fall chute (there is no real proof that they are), such damage may be about as equally likely for either air-entry attitude.

The minimum shot-to-shot time spacing for acoustic measurements using 800 foot SUS must be maintained at 1/2 minute to hold the likelihood of overlapping detonations at an acceptably low level. Detonation overlap, which still occurs at this spacing, is caused by early (shallow) firing and/or by late (slow descent rate) firing, and results in the loss of data from at least two shots each time that it occurs. The time interval limitation is important in measurements conducted from aircraft for it established a maximum density of data points in terms of propagation range and bottom reflection grazing angle. Shipboard measurements are normally unaffected by the problem of shot overlap because events transpire at rates about one to two orders of magnitude slower than aboard aircraft.

RECOMMENDATIONS

The performance obtained from the current stocks of standard MK 61-0 SUS is sufficiently good to warrant their continued use in ocean acoustic measurements. However, there is room for improvement if new SUS are to be specifically designed for acoustic measurements instead of for active echo ranging systems that had less stringent requirements on performance factors such as detonation depth and sink rates.

Any new SUS must be designed to be as safe to handle as the existing stock.

The reliability of the firing depth selection device requires improvement. This may call for minor engineering changes.

The cause of an abnormally slow sink rate in some SUS, which places a constraint on aircraft measurement techniques and which causes the loss of some data, should be identified and remedied.

SUS OPERATION AND PERFORMANCE CHARACTERISTICS

Detailed information on the construction, use and performance characteristics of MK 61-0 and other SUS may be found in reference 2. The characteristics that are relevant to this examination are:

1. Main Charge - 1.8 lb (0.82 kg) TNT

2. Sink Rate - 16.8 feet/seconds to 800 feet

3. Firing Depths

   Shallow - 60 feet ± 10 feet
   Deep - 800 feet ± 80 feet

4. Firing Time (water entry to detonation)

   Shallow - 3 seconds ± 1 second (air launch)
   - 4 seconds ± 1 second (surface launch)
   Deep - 46 seconds ± 5 seconds

A SUS is in a safe condition until reaching a depth of 18 feet minimum + 25 feet, at which point an arming piston has been forced by water pressure to a position where the firing mechanism can strike the primer charge. In storage, an external arming wire restrains the arming piston from moving. If the wire remained in place, the SUS could not fire at any depth. A drag plate, clipped loosely to the SUS's tail-fin assembly, is attached to the arming wire and pulls the wire out when the SUS enters the airstream during an aircraft launch.

The SUS's firing mechanism is also activated by water pressure acting on a piston. There are actually two concentric pistons in the MK 61-0 mechanism. The smaller center piston is the deep firing piston, and the larger outer piston is the shallow firing piston. They both bear on the next stage in the firing mechanism, but when a hairpin-shaped wire is slid crosswise into the nose of the SUS, it engages a groove in the outer circumference of the shallow firing piston, thus preventing it from assisting the deep firing piston in depressing the firing mechanism. The SUS is provided with the depth setting wire in place, and the SUS will therefore fire at the deep setting if the wire is not removed. There are bends in the wire that hold it in place, and a strip of adhesive tape is also often placed over the nose to secure it.

EMPLOYMENT IN ACOUSTIC MEASUREMENTS

In an operation that the NAVAIRDEVCEN has conducted 202 times to date, a string of sonobuoys and MK 61-0 SUS are aircraft-launched in a pattern typified by figure 1. During the launch sequence, the aircraft altitude, heading, and ground speed are held constant. Nominal altitude is 5000 feet, but may be anywhere between 4000 and 6000 feet as dictated by weather and visibility. Ground speed is within the range 180 to 220 knots.

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[2] *Tech Manual NAVAIR 11-1-107 (first revision), 15 Sept 1971. Description, Operation and Handling Instructions: Signals, Underwater Sound (SUS).*

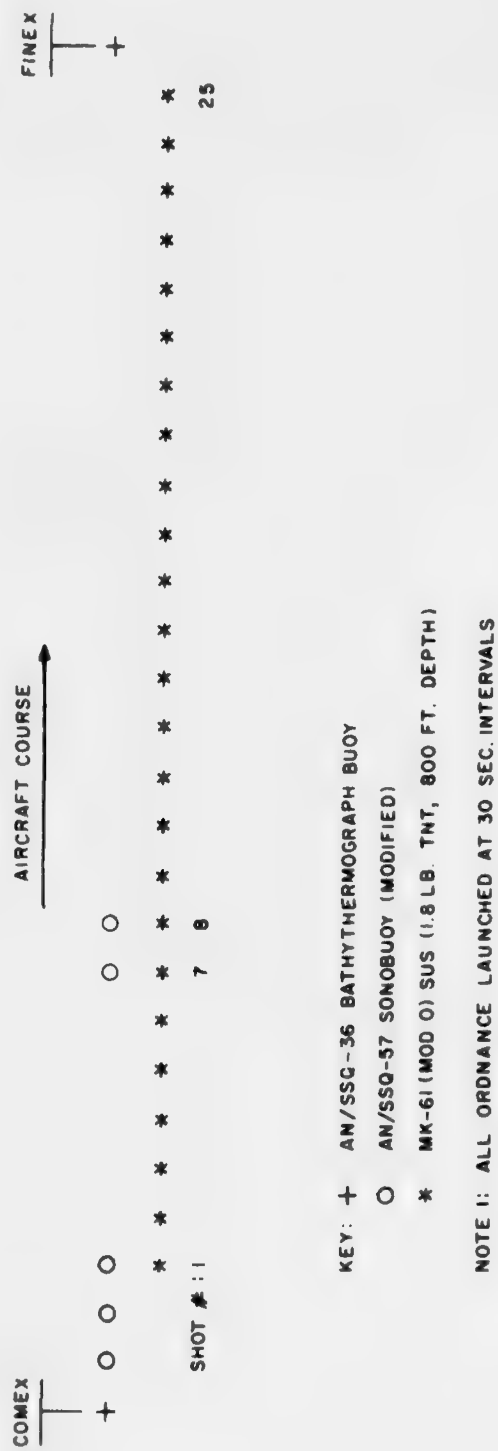

Figure 1. Bottom Loss Measurement Ordnance Launch Pattern.

The SUS are launched from standard magazine load aircraft SUS launchers or via free-fall chutes.

The exact time that each sonobuoy and SUS is launched is noted on a tape recording via a tone burst. Nominal launch interval for all units is 30 seconds. The acoustic outputs of the sonobuoys are also recorded on the above mentioned tape.

Statistics have been compiled on the performance of 2697 MK 61-0 SUS that were set for deep detonation and expended in 108 acoustic bottom loss measurement runs conducted between March 1971 and April 1975. The SUS were grouped into six categories:

1. SUS that fired within the depth tolerance band set forth in the performance specification (800 feet ± 80 feet).

2. SUS that, although set for deep firing, detonated in the shallow depth range (60 feet to ± 10 feet).

3. SUS that detonated somewhere between the deep and shallow ranges (70 to 720 feet).

4. SUS that detonated below the deep range.

5. Duds - No apparent explosion.

6. Unknown - The two most common circumstances that caused SUS to be placed in this category were:

a. detonation of the first SUS of a measurement run before the sonobuoy hydrophone has fully deployed, and

b. detonation of two SUS so close together in time that it was not possible to tell what acoustic arrival came from which SUS.

The results of this categorization appear in table I. They are expressed in terms of number of SUS in each category, percentage of total sample population, and percentage of the sample population that is other than "normal," i.e., excluding the group defined by paragraph 1 above. It is evident that the only significantly large groups are composed of SUS that fired at the shallow depth, and duds.

Of the 15 SUS that appeared to go abnormally deep before firing, there is evidence that 12 were probably partial detonations. This was deduced from the fact that the sink times were too short to allow the SUS to reach depths that were computed from an assumed full charge weight and measured bubble periods.

Measurement of the bubble pulse period was made on a subset of the sample population. This group, consisting of 428 shots, comprised the "normal" detonations from one measurement deployment conducted during April 1975. Visicorder strip charts and Polaroid photos of oscilloscope traces showing the shot returns were used to obtain accurate measures of the bubble periods, and firing depth was computed as:

TABLE I

PERFORMANCE RESULTS FOR 800 FT MK 61-0 SUS

Firing Depth Range (ft)	Quantity	% of Total	% of Total Abnormal
800 ± 80 (normal)	2181	80.9	-
60 ± 10	310	11.5	61.1
70 to 720	4	0.15	0.8
>900	15*	0.55	2.9
Duds	154	5.7	30.4
Unknown	33	1.2	6.5

* Includes 12 partial detonations

Total Abnormal	516	19.1	100.0

$$D = \left(\frac{W^{1/3}}{0.23\ Tb}\right)^{6/5} - 33$$

where:

D = firing depth in feet
Tb = bubble pulse period in seconds
W = charge weight in pounds (1.8 lb)

The estimated firing depth measurement accuracy achieved was ± 7.5 feet.

The distribution of apparent firing depths is presented as a frequency histogram in figure 2 and as a cumulative distribution curve in figure 3. Although the distribution peaks at a depth of 800 feet, the mean value is 794.5 feet. The fact that the mean firing depth is on the shallow side of the nominal firing depth is consistent with the findings of a CHURCH ANCHOR report.[3] In that study it was found that the mean burst depth for MK 82 SUS (300 feet) was 290 feet, and the mean burst depth for MK 61 SUS set for 60 feet was 58 feet.

Sink time (water entry to detonation) estimates, Ts, for the SUS were computed as:

$$T_s = T_t - T_a - T_p$$

where:

T_t - total elapsed time from aircraft launching of the SUS to receipt of the detonation at a sonobuoy.

T_a = free-fall from aircraft to water.

T_p = acoustic propagation time from point of detonation to sonobuoy.

The free-fall times were computed for a drag-free descent (17.7 seconds from a 5000 foot altitude). Trial computations made with a SUS drag coefficient derived from unpublished empirical data increased the descent times by only 1.5 to 2.0 seconds. The in-water acoustic travel times were computed from previously determined SUS-sonobuoy ranges and an average sound velocity. The simplifications made in the calculation of sink times compromise their accuracy slightly, but not so much as to destroy the credibility of the following observations.

A frequency histogram of the sink times for the deep (800 feet nominal) SUS appears as figure 4. It is interesting to note that the distribution is bimodal. One peak occurs at 48 seconds which corresponds closely to the specified descent time of 46 seconds ± 5 seconds. The second, smaller peak occurs at 59 seconds. There is evidently something that happens to some SUS that prolongs their descent times. Possible causes, as suggested in the SUS manual, and by personnel at the Naval Weapons Station, Yorktown, Virginia.

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[3] *Weinstein, M.S. and Hecht, R.J., 5 June 1974. SUS Quality Assessment; Underwater Systems, Inc.*

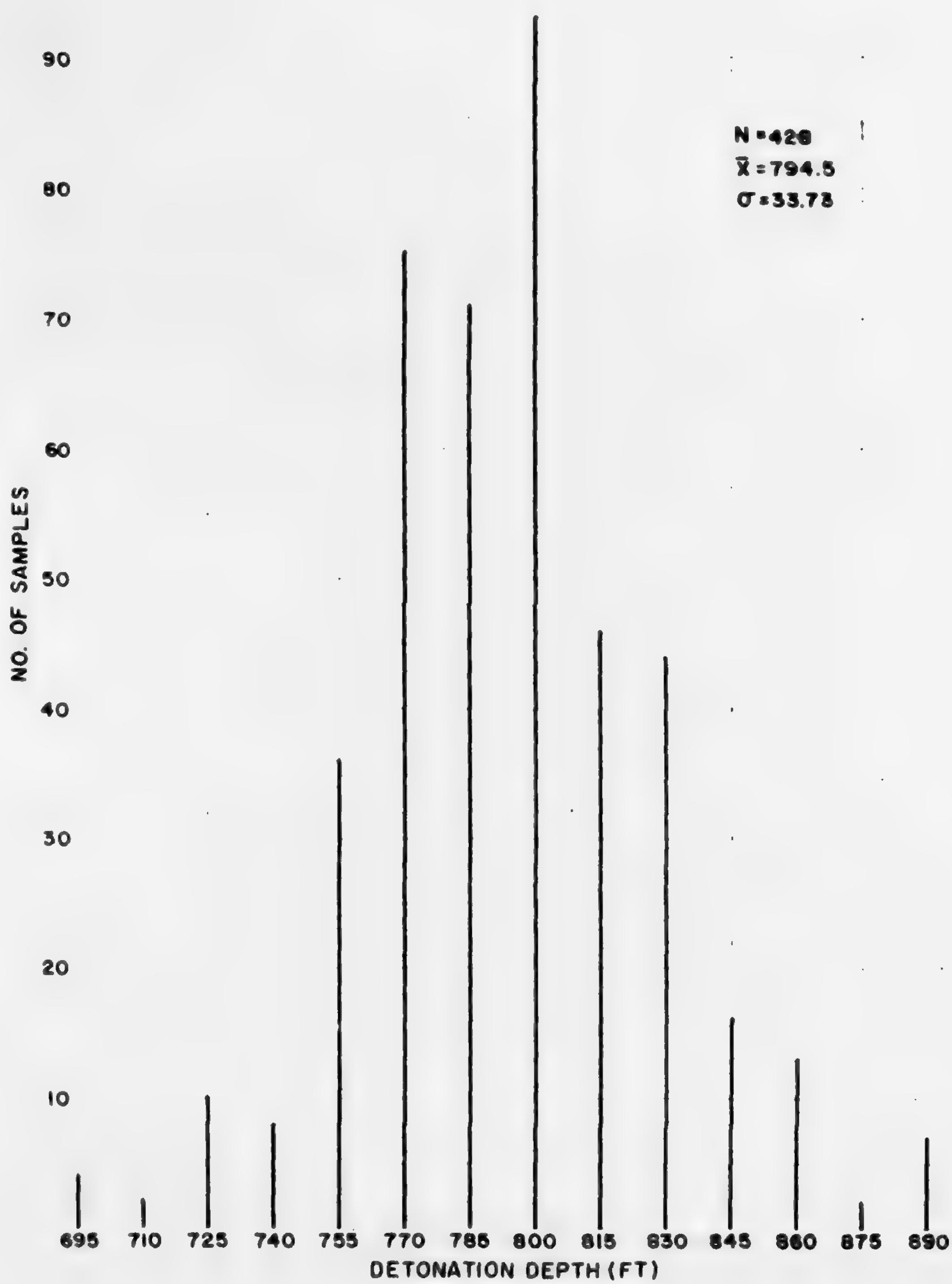

Figure 2. Frequency Distribution of Detonation Depths Near 800 Feet.

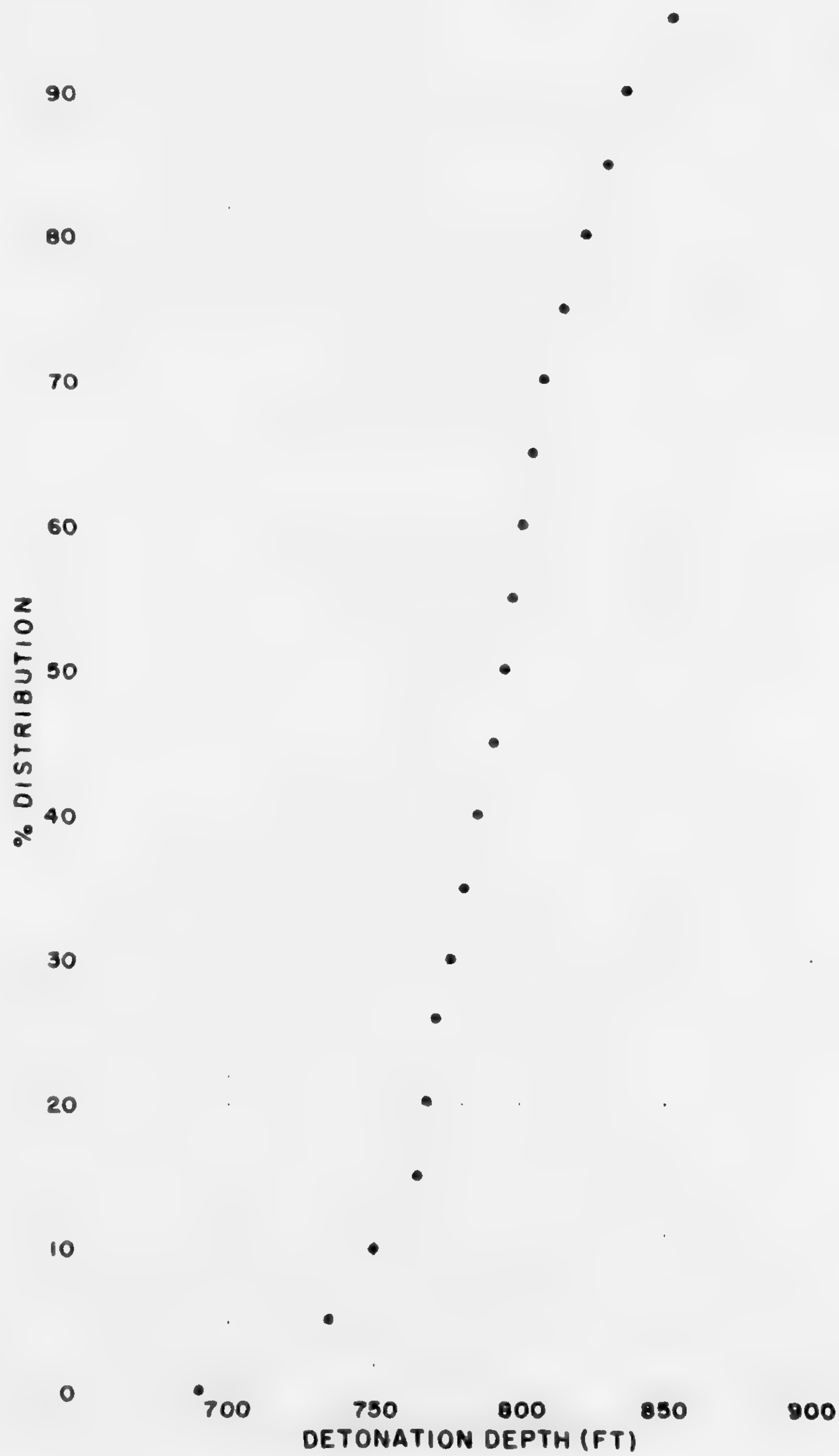

Figure 3. Cumulative Distribution of Detonation Depths Near 800 Feet.

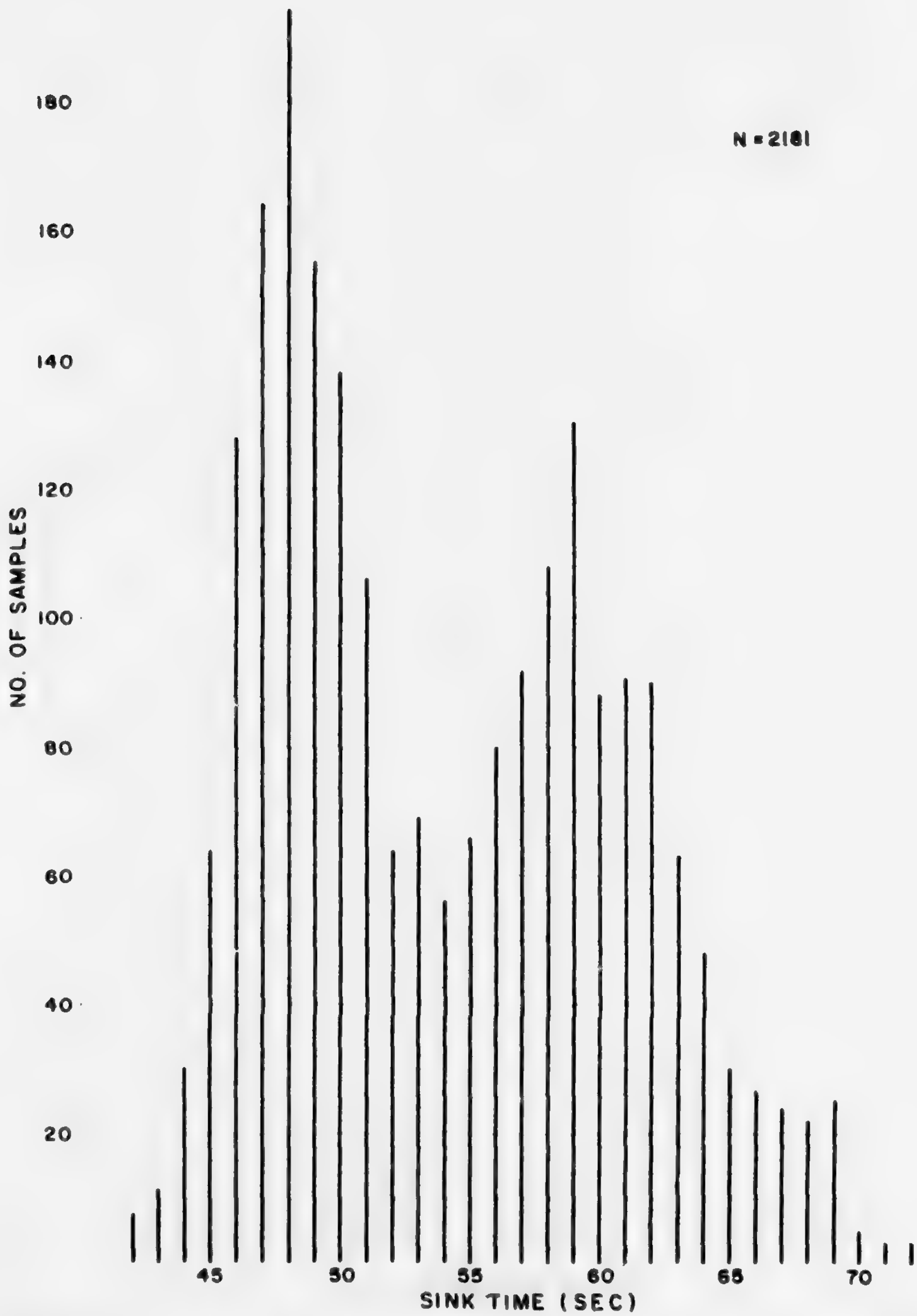

Figure 4. Frequency Distribution of Sink Times to 800 Foot Depth Range.

are an increased drag caused by entangled arming wire/drag plate assemblies or drag and/or a spiraling descent caused by damaged tail fin/shroud assemblies. During some acoustic measurement deployments, the arming wire assemblies were intentionally removed by the ordnanceman prior to launch, but slow descents were still found among the resultant shots.

The sink times of 248 deep SUS that detonated within the depth range of shallow (60 feet nominal) shots were also calculated by the above method, and the results appear as a frequency histogram in figure 5. Class intervals in the histogram are 1 second wide. The distribution peaks at 4.5 seconds, and the sample mean is 4.2 seconds. This is slightly longer than the 3 seconds ± 1 second specified for shallow shots. The small difference between specified and estimated times for the shallow detonations, where the sink time is a relatively small component in the equation, also imparts a measure of confidence in the other time component estimates (air descent and acoustic travel).

Sink rates for the deep shots were obtained from their firing depths and sink times. As expected, the frequency histogram, figure 6, of these values reflects the bimodal distribution of the sink times. The major peak, corresponding to the apparently normally descending SUS, occurs at 16.75 feet/second, agreeing well with the specified 16.8 feet/second rate. The minor peak in the distribution occurs at 13.75 feet/second.

DISCUSSION OF SHOT SPACING LIMITATION

Accurate knowledge of acoustic bottom loss at the lower grazing angles is of especial importance in predicting and understanding the performance of many sensor systems because of a combination of factors. Most bottom reflecting acoustic energy that succeeds in traveling over long distances is that which has encountered the bottom at small angles, traveling comparatively large distances between reflections and, therefore, incurring the fewest chances for bottom loss in a given distance. Variations in the magnitude of bottom loss are greatest at the lower angles; there is, at times, a significant amount of detail in the low angle bottom loss characteristic. Since the amount of loss at the smaller angles can well determine whether a distant acoustic source will be detected via a bottom reflected path, the best possible definition of low angle loss characteristics is required.

In bottom loss measurements, angular resolution is a function of several variables in the geometry of the experiment. In this examination, certain of these - SUS and hydrophone depth - are nominally fixed, and others - ocean depth and velocity profile - are variable but measurable. To obtain a measure of bottom loss as a function of grazing angle, measurements are made at various source-receiver ranges. From an aircraft platform that is launching all the receivers (sonobuoys) and sources (SUS) in one straight line pass to obtain a best estimate of their spacing, the minimum range increments are dependent upon how frequently the SUS can be launched and exploded without having their acoustic outputs become intermingled and confused.

Ideally, the minimum permissible time interval between shots should be the duration from onset of the direct acoustic arrival to the tail of the last usable bottom return. This duration is geometry dependent. As such, for a

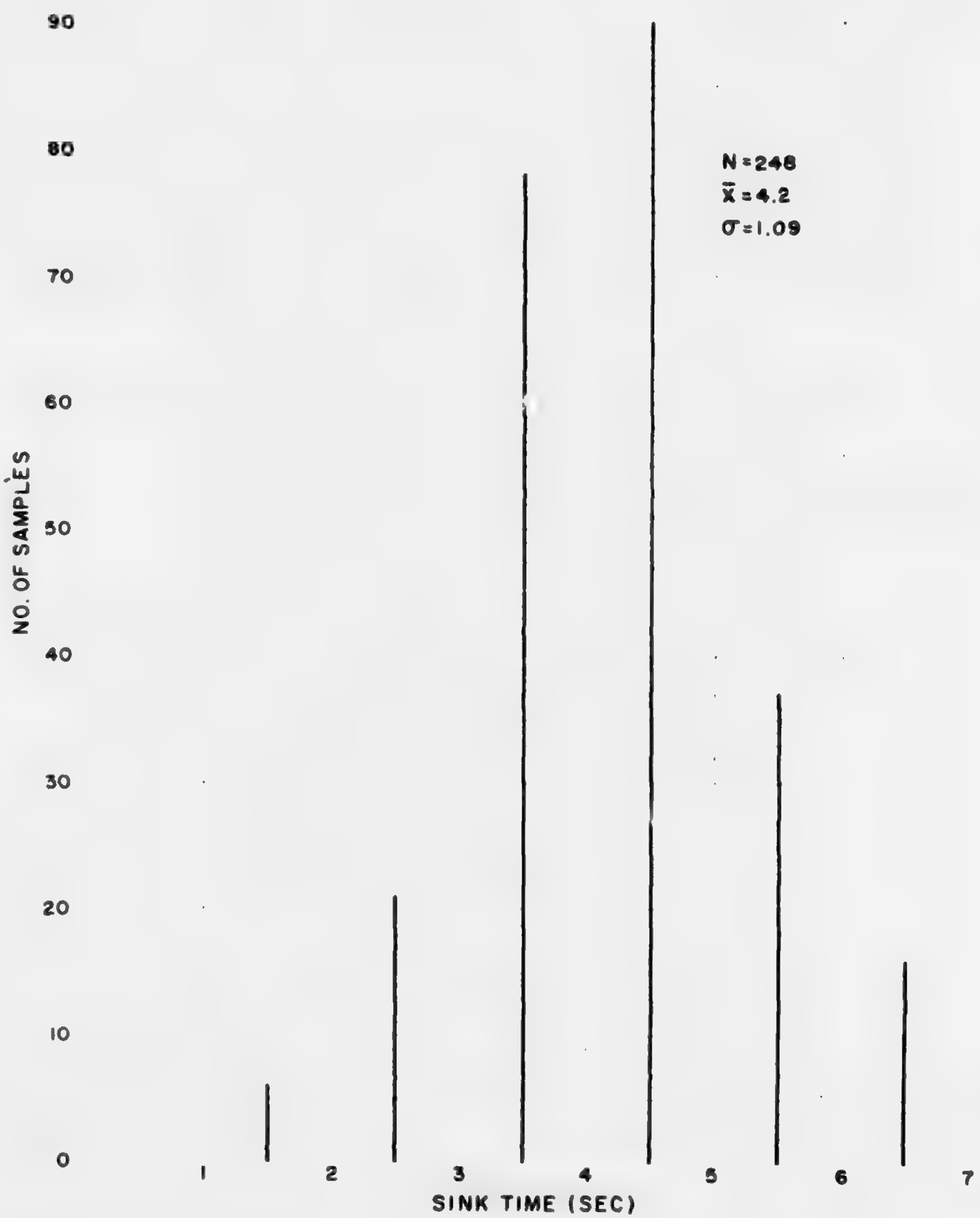

Figure 5. Frequency Distribution of Sink Times to 60 Feet Depth Range.

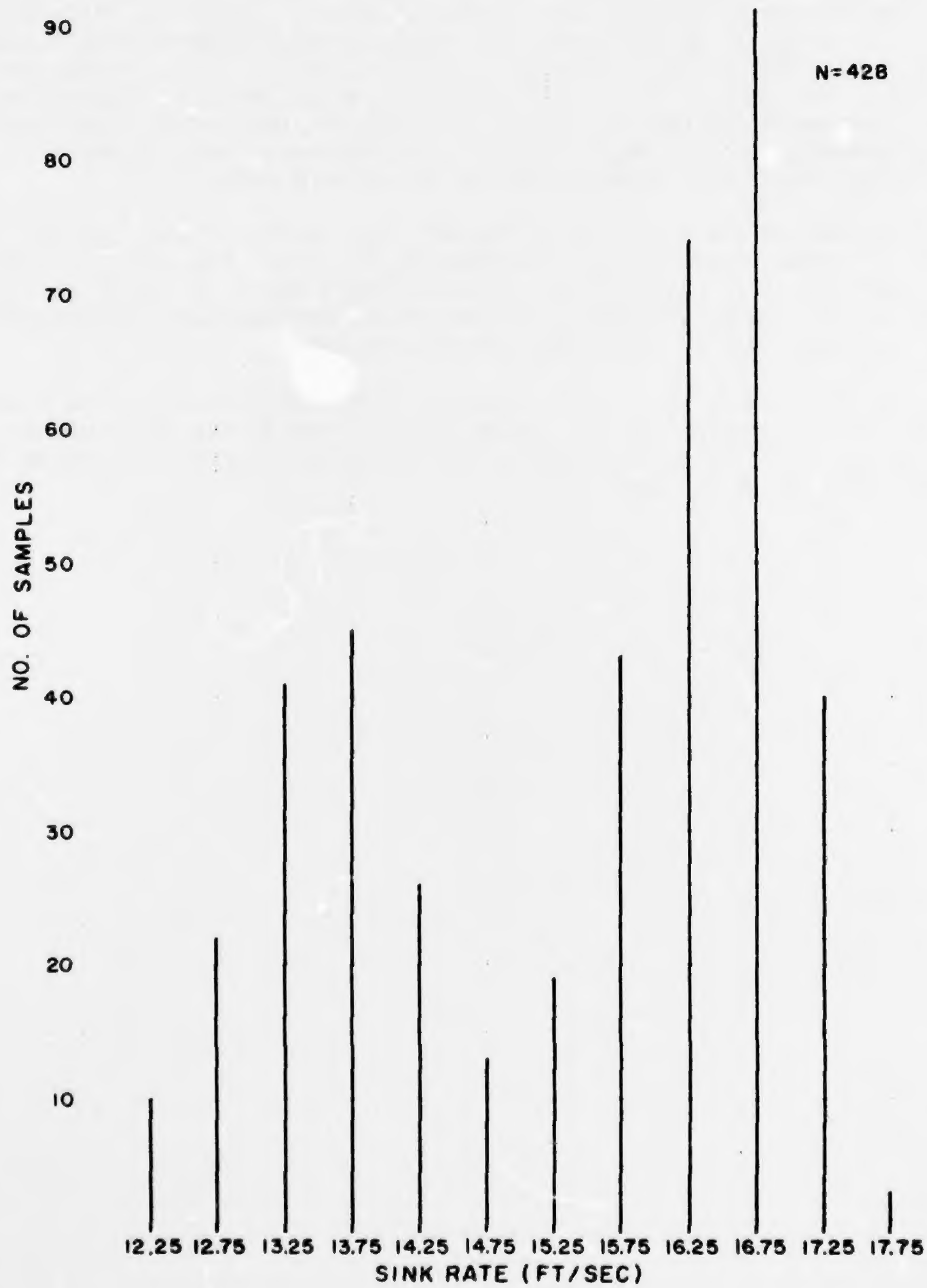

Figure 6. Frequency Distribution of Sink Rates to 800 Feet Depth Range.

progression of shots at ever increasing ranges from the acoustic sensor, the duration gradually diminishes from some maximum value. In the NAVAIRDEVCEN measurements conducted in deep ocean areas, the maximum time interval required to receive the direct through third bottom returns is typically 20 to 25 seconds, at ranges of about 4 kyd. At ranges corresponding to first bottom grazing angles smaller than 40 degrees, the interval is typically shorter than 15 seconds. As seen in the curve of figure 7, which depicts a typical relationship between first bottom grazing angle and the horizontal range between SUS and sonobuoy, grazing angles below 40 degrees cover most of the range out to the first convergence zone, where the bounce mode ends.

Tolerances on SUS sink time to the 800 foot depth is specified as ± 5 seconds. If this tolerance were realized at all times, the acoustic outputs of SUS launched at 30 second intervals would never overlap, and no data would be lost to this cause. However, shallow detonations and slow sinking SUS, singly or in combination cause the loss of some data.

It is also conceivable that, with a tighter sink time tolerance, the launch interval for measurements at grazing angles less than 40 degrees could be shortened to as little as 20 seconds, thus reducing the practical range increments from 3.5 to 2.3 kyd.

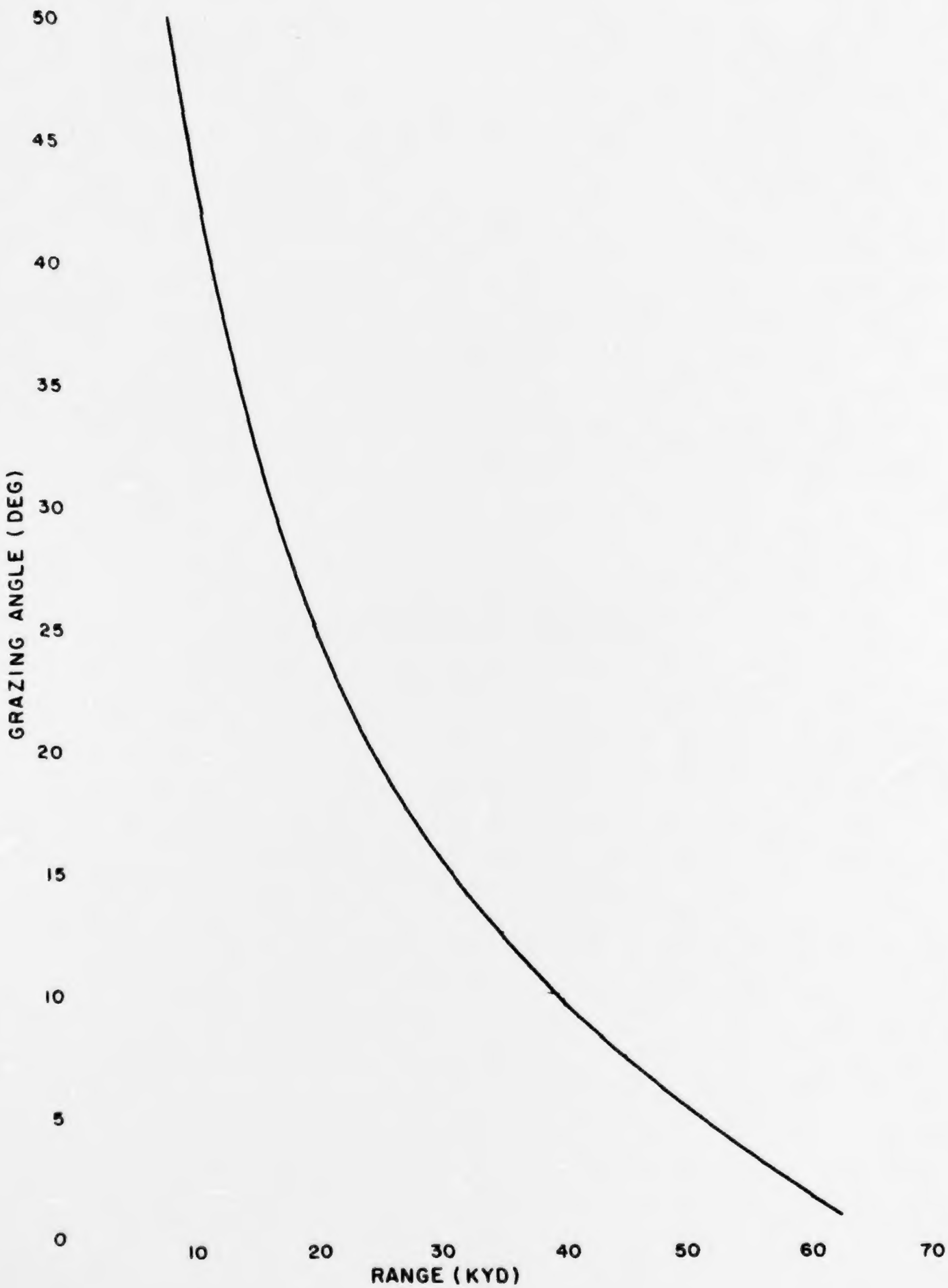

Figure 7. Typical First Bottom Bounce Grazing Angle as a Function of Range.

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